CHAPTER 8

Aircraft Accident Characteristics

OVERVIEW

There has long been a general consensus within the airport industry that some degree of safety concern exists beyond the typical boundaries of an airport and its runway protection zones. This is particularly true with regard to general aviation airports which, compared to major airline facilities, typically control less land beyond the runway ends and have higher rates of aircraft accidents. Also, land use compatibility planning at most general aviation airports is not dominated by the extensive noise exposure areas common to airline (and military) airports.

This chapter summarizes a variety of data regarding the characteristics of aircraft accidents including:

- Aircraft and pilot performance factors affecting aircraft accidents;
- The location of aircraft accidents near airports; and
- The nature of aircraft accident impacts.

A major element of the 1993 edition of the *Airport Land Use Planning Handbook* was the development of a geographic database for general aviation aircraft accidents. Until the 1993 *Handbook* was published, airport and land use planners lacked a source of data to utilize when attempting to develop safety compatibility criteria for the vicinity of airports. For the first time, the locations of general aviation aircraft accidents relative to the runway used was known.

The work of compiling the accident data was conducted by the Institute of Transportation Studies at the University of California, Berkeley. The major findings of this research are incorporated into the discussion here.

Neither the National Transportation Safety Board (NTSB), which is the primary repository of aviation accident data in the U.S., nor the Federal Aviation Administration routinely compile data in this manner. For both agencies, accidents are investigated for aeronautical purposes to determine ways of improving the design and operation of aircraft and airports and to foster better pilot skills and techniques. If land use factors are examined at all, it is done only in a manner incidental to the primary purpose of the investigation.

Aircraft *accidents* are defined as events associated with flight which result either in fatal or serious injury to a person (either on board the aircraft or on the ground) or in substantial damage to the aircraft. Events with less serious outcomes are classified as *incidents*. Taken together, accidents and incidents are referred to as *mishaps*.

As part of this 2002 edition of the *Handbook*, the accident location database was expanded. The total number of data points was increased from 400 to 873. A statistical analysis of the expanded accident database is summarized in this chapter. Also included here is information describing other characteristics of aircraft operations and accidents. This update also significantly expands the documentation of commercial airline aircraft accidents. Chapter 9 then evaluates this data in the specific context of airport land use commissions and safety compatibility planning issues.

Aircraft Limitations and Pilot Actions

The emphasis in this discussion is on emergency conditions in which the aircraft can be maintained under at least some measure of pilot control. Most of the performance characteristics described here are not applicable in situations where the aircraft is incapable of being controlled (because of mechanical failure or damage resulting from collisions with obstacles or other aircraft, for example). For a discussion of normal, nonemergency, aircraft operational characteristics and flight procedures, see Chapter 6.

Chapter 6 outlined the parameters of normal operation of aircraft in the vicinity of airports. That discussion, presented in the context of airport noise, is also pertinent to safety compatibility issues in that it addresses where aircraft regularly fly. The additional factors of importance to the topic of safety are the performance limitations of aircraft and the actions of pilots which can cause or contribute to emergency situations. A review of these factors helps to provide some understanding of why aircraft accidents occur where they do.

Airplane Emergencies

Broadly speaking, aircraft operations emergencies can be divided into two groups: situations in which the pilot's control of the aircraft directly creates the emergency and situations in which some other condition causes an emergency to which the pilot must react. Among airport-vicinity, general aviation airplane accidents in the first of these groups, the most common is pilot failure to maintain sufficient flying speed. This usually results in a stall, and potentially a spin and uncontrolled descent. In the second group, common accident factors include adverse wind and weather conditions and loss of power (complete or partial engine failure for either mechanical reasons or due to lack of fuel).

Airplane Performance Limitations

When not prevented by mechanical or structural damage, the capability of an airplane to remain under pilot control while flying is largely dependent upon the plane's airspeed. Even in situations where a complete engine failure has occurred, a plane will not go out of control and drop from the sky if sufficient speed is maintained and enough altitude is available to give the pilot a chance to react. Even large, air carrier jet aircraft have been landed without functioning engines.

Most light airplanes are capable of gliding 500 to 1,000 feet for every 100 feet of altitude (altitude is lost more quickly in turns than when gliding straight ahead, however). At a 1,000-foot traffic pattern altitude, for example, a light airplanes could travel one to two miles before reaching the ground.

One major difference among airplanes is between single-engine and multi-engine types. An obvious, but very important, distinction between the two is that a multi-engine aircraft can experience an engine failure without having a complete loss of power. Although the asymmetrical thrust plus drag from an inoperative engine(s) reduce performance, most multi-engine aircraft can hold altitude or even continue to climb if one engine fails. For smaller piston twins with less power, the functioning engine may do no more than extend the glide distance, provided that the pilot keeps the aircraft under control.

For a single-engine plane, the critical airspeed is its *stall speed*. A multi-engine plane has two additional milestone speeds: *minimum control speed* and *best single-engine rate of climb speed*. These critical airspeeds are significant regardless of the flight mode of the aircraft: taking off, landing, or maneuvering at low speeds. As noted, however, these speeds are particularly important for a pilot to watch when an engine failure occurs, especially on takeoff.

➤ **Stall Speed (V_s)**—This is the minimum steady flight speed at which an airplane, either single- or multi-engine, can fly. At lower speeds, the flow of air over the wing does not generate enough lift to match the aircraft's weight. If an engine failure occurs before this speed is reached during the takeoff run, the airplane would remain on the ground and maximum braking would need to be applied to bring the plane to a stop. If the engine failure occurs while the airplane is airborne, it is essential for the pilot to keep the aircraft above stall speed. The airplane's speed can be controlled by adjusting its pitch and, on a multi-engine aircraft, by use of the remaining engine(s). By staying above stall speed, an airplane can potentially be guided to a successful emergency landing. A significant factor to note is that an airplane's stall speed is higher during a turn (that is, the airplane can stall more readily) than it is in straight flight.

➤ **Minimum Control Speed (V_{mc})**—Below this speed, a multi-engine airplane cannot be controlled with full power on the remaining engine(s) with the critical engine inoperative. Airflow across the rudder does not generate enough yawing force to overcome the asymmetrical thrust of the remaining engine(s) operating away from the aircraft centerline. Engine failure below this speed requires a reduction in power on the good engine(s) in order to maintain directional control.

V_{mc} is typically attained while the aircraft is either still on the runway or only a few feet above it. During a takeoff, the aircraft would either remain on the ground or would, if properly handled, return immediately to the ground in a controlled manner. Maximum braking would then be applied.

➤ **Single-Engine Climb Speed (V_{yse})**—V_{yse} is the speed at which a twin-engine airplane operating on one engine can attain the best rate of climb (or, for some aircraft, the slowest rate of descent). If an engine fails below this speed, it is possible to stretch a controlled descent as long as a speed of V_{mc} or better is maintained. The aircraft will quickly return to the ground, however. Engine failure at a speed above V_{yse} may not necessitate a forced landing because many twin-engine airplanes are capable of using the remaining engine to climb to an altitude from which a return to the airport for a safe emergency landing can be made.

Pilot Actions

As alluded to above, pilot actions under emergency circumstances are a major determinant of whether an accident will result and, if so, how severe it will be. Pilots are taught a set of procedures to follow if, for example, an engine stops running. Most critical is to keep the aircraft under control. Next, time permitting, is to attempt to determine the problem and, if possible, restart the engine. If an emergency landing becomes inevitable, the pilot should then try to find a reasonable spot to put the aircraft down.

When an engine failure occurs while approaching or departing an airport, the initial reaction of most pilots is to attempt to land on the runway. For small aircraft, a runway landing should be possible if a landing traffic pattern is flown at a normal altitude and distance from the runway. If larger, multi-engine aircraft lose an engine, most are capable of continuing the flight to a normal landing. Of course, on takeoff, the aircraft is headed away from the runway. For single-engine aircraft, and some piston twins, a runway landing becomes difficult or, at low altitudes, impossible. As mentioned above, an airplane's descent rate and stall speed both increase while turning. This characteristic is the reason why attempting to return to the runway with a single-engine aircraft following an engine failure while on takeoff can have disastrous consequences.

In certain respects, maintaining control of a multi-engine airplane, especially a twin-engine airplane, is more difficult following an engine failure than it is with a single-engine airplane. With the latter, a complete engine failure unavoidably results in descent (assuming the engine cannot be restarted) and the pilot has no choice but to respond accordingly. With a twin-engine aircraft, however, many pilots think that they can keep the aircraft in the air even when an engine failure occurs on takeoff at low altitude. Many light twins, though, do not have enough power to continue to remain airborne on one engine. Moreover, because of a twin-engine airplane's asymmetrical thrust characteristics, lack of immediate and proper pilot response during an engine failure on takeoff is more likely to lead to an uncontrolled accident than is the case with a single-engine plane. For many small, twin-engine airplanes, the prudent course of action if an engine fails at low altitude on takeoff is to reduce or shut off power to the good engine and glide back to the ground just like would be done in a single-engine plane. For larger twins and multi-engine aircraft, there is typically sufficient power available from the remaining engine(s) and sufficient control authority to continue the flight.

In the few moments that a pilot may have available in which to select an off-airport emergency landing site, there is no certainty that the best site can be spotted—particularly at night or under IFR weather conditions—or that it can be reached. A large, flat, open area is preferable; but, if one cannot be found, a small open space or a street or parking lot are often the best candidates. Usually, an effort will be made to avoid people, buildings, large trees, and other such objects. Smaller objects, such as ditches and wires, may not be obvious until it is too late to avoid them. Luck consequently plays a significant role in such circumstances.

Helicopter Emergencies

As with airplanes, airspeed and altitude are also critical determinants of whether a pilot can maintain control of a helicopter in the event of an emergency involving an engine failure. Although helicopters cannot glide as far as airplanes can (a typical glide ratio at optimum airspeed is 300 to 500 feet horizontally per 100 feet of altitude lost), neither do they necessarily crash if an engine should fail while in flight. Indeed, because helicopters can safely descend much more steeply than airplanes, the area needed for an emergency off-airport landing can be much smaller. Also many of the newer, moderate-size helicopters—especially turbine-powered ones—have twin engines driving the main rotor.

The procedure used for emergency helicopter landings following an engine failure is known as *autorotation*. In simple terms, autorotation involves disengaging the main rotor from the engine drive system, thus enabling the blades to rotate freely. Air traveling upward through the blades causes them to continue rotating and producing lift to slow the descent. Also, the rotation of the main rotor drives the tail rotor to allow directional control to be maintained.

The altitude from which an emergency autorotation descent can successfully be conducted is dependent upon several factors with airspeed generally being the most significant. From near cruising speeds, most helicopters can perform an autorotation from an altitude of 100 feet or even slightly less. However, when hovering at zero airspeed, 500 feet of altitude may be needed. In effect, the altitude must be traded for forward speed before successful autorotation can be accomplished.

AVAILABILITY OF ACCIDENT LOCATION DATA

Historical Data

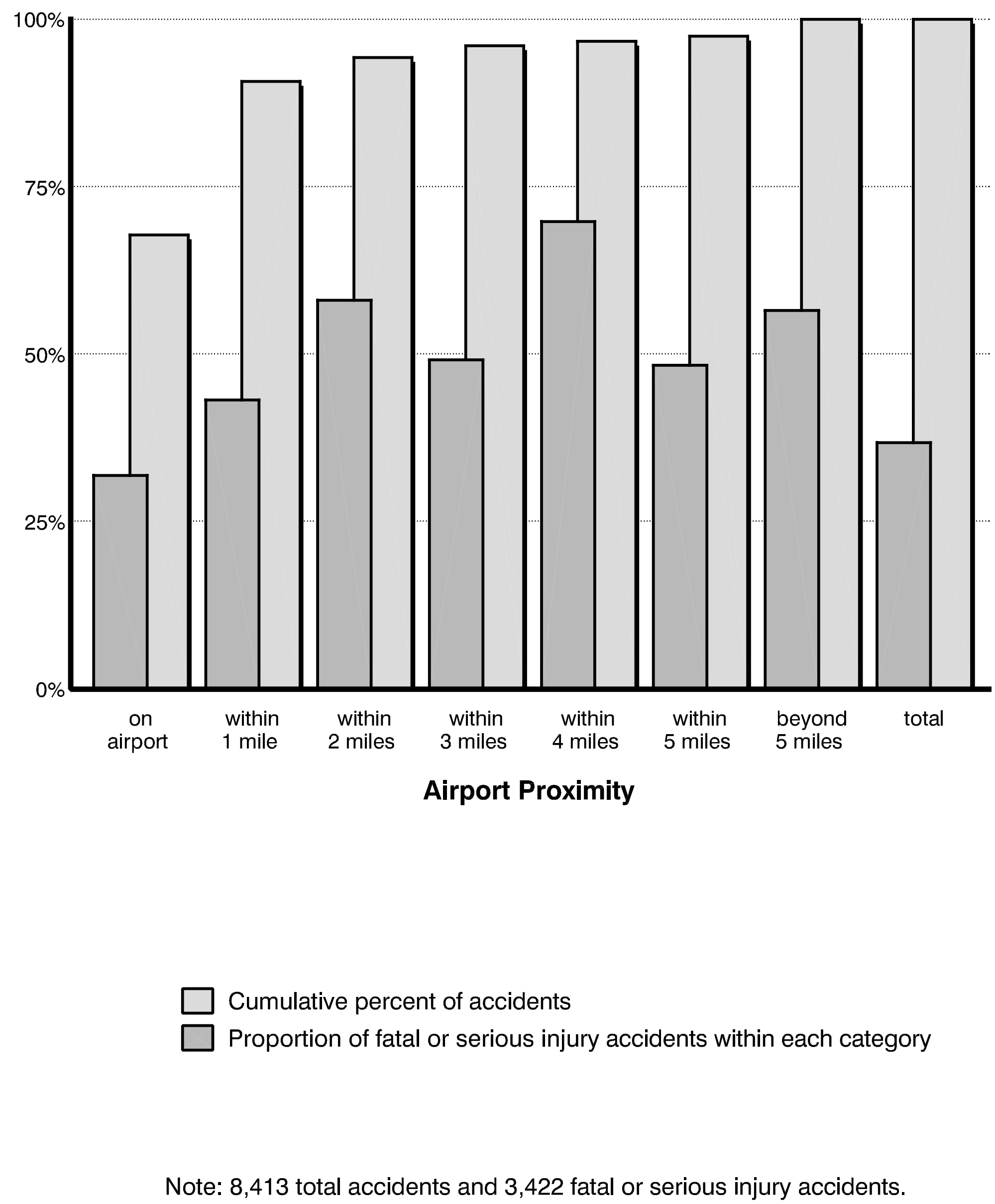
A vast amount of data on aircraft accidents is available from the National Transportation Safety Board, the primary repository of aircraft accident data in the U.S., and from the Federal Aviation Administration. As noted at the beginning of this chapter, however, data regarding the location of aircraft accidents is scarce.

Approximate Location Data

For each accident which the National Transportation Safety Board investigates, a *Factual Report* (NTSB Form 6120.4) is completed. Included in the report are data entries for *distance from airport center* and *direction from airport*. This information could be valuable for land use compatibility planning purposes if it were precisely documented. Its usefulness is limited, however, because the accident investigation form requires only that the data be given to the nearest statute mile.

A compilation of the NTSB accident proximity data for the years 1990 through 2000 for general aviation accidents is shown in Figure 8A. Figure 8B shows similar data for commercial aircraft.

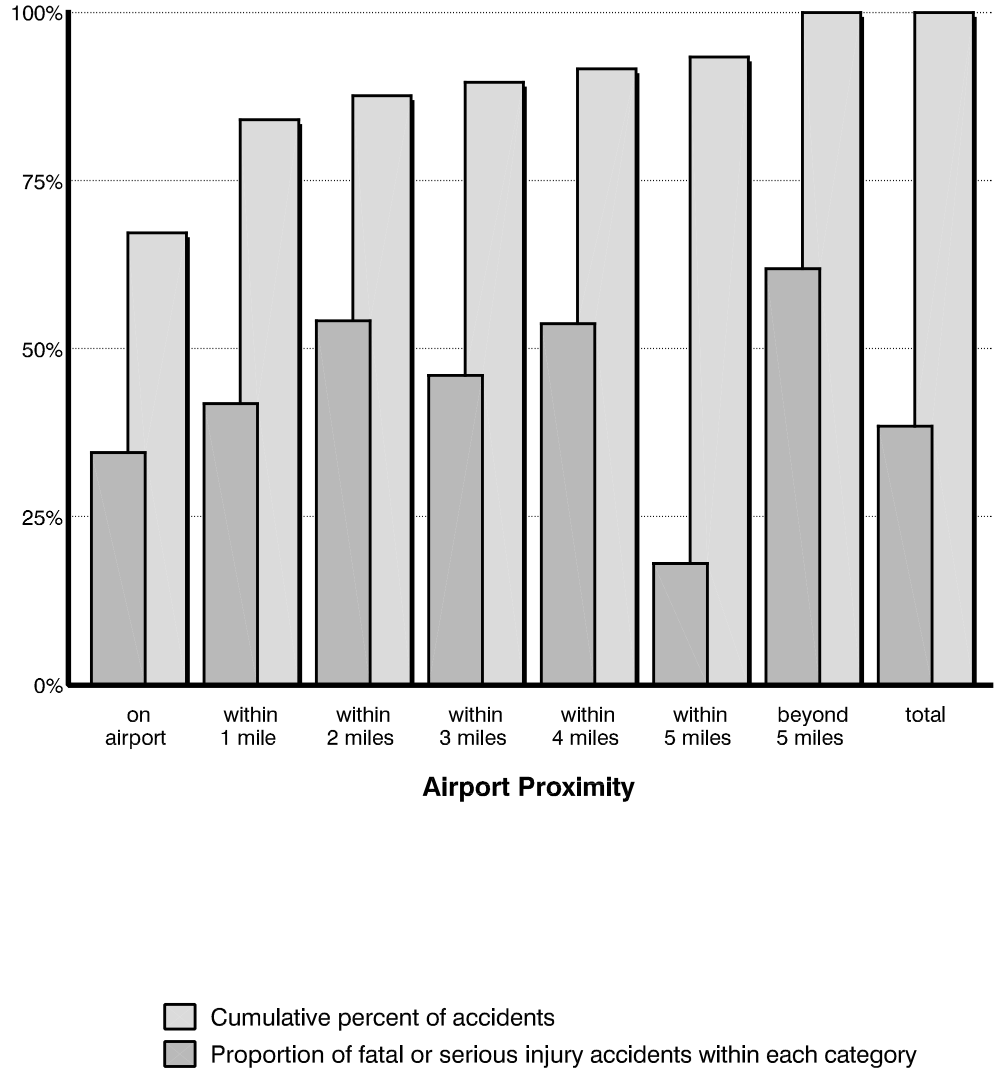
The NTSB has not published this in formation for later years in its *Annual Review of Aircraft Accident Data*. Nevertheless, the consistency of the numbers for the years examined suggests that the average remains basically valid today.



Source: Data compiled from NTSB Aviation Accident Database: General Aviation—Calendar years 1990–2000

FIGURE 8A

Proximity of General Aviation Accidents to Nearest Airport



Note: 650 total accidents and 251 fatal or serious injury accidents.

Source: Data compiled from NTSB Aviation Accident Database: Air Carrier—Calendar years 1990–2000

FIGURE 8B

Proximity of Air Carrier Accidents to Nearest Airport

The data reveals that over two-thirds of both general aviation (68%) and commercial (67%) aircraft accidents take place on an airport. Another 3% of general aviation and 7% of commercial aviation are en route accidents—defined here as ones occurring more than 5 miles from an airport. This leaves 29% of general aviation and 26% of commercial aviation accidents which can be classified as airport-vicinity accidents, potentially including some en route accidents which happened to take place within 5 miles of an airport.

A somewhat more detailed set of data on commercial aircraft accident locations is one recently gathered by researchers in the United Kingdom (NATS–1997). Separate graphs show runway proximity of landing and take-off accidents in two dimensions: distance from the runway end and distance from the extended runway centerline (see Figure 8C).

Precise Location Data

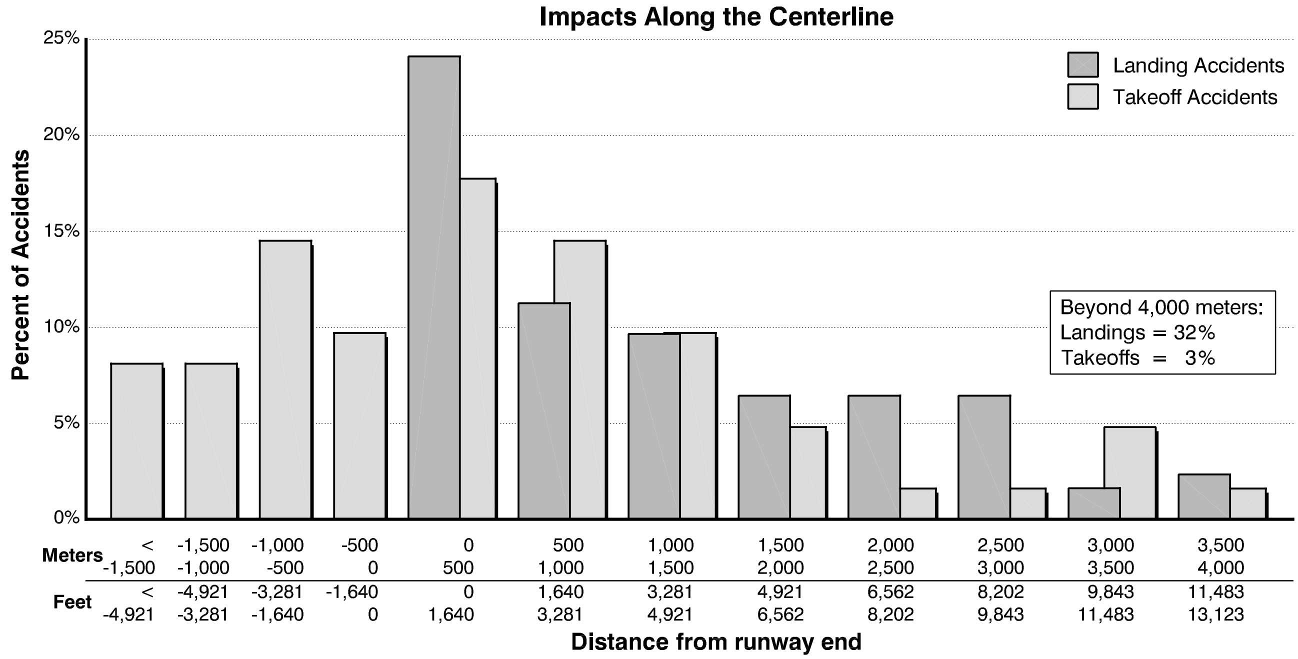
Several previous research efforts endeavored to document the type of precise aircraft accident location data which would be pertinent to airport land use compatibility planning. Although each of the studies provides significant information, all are limited in scope.

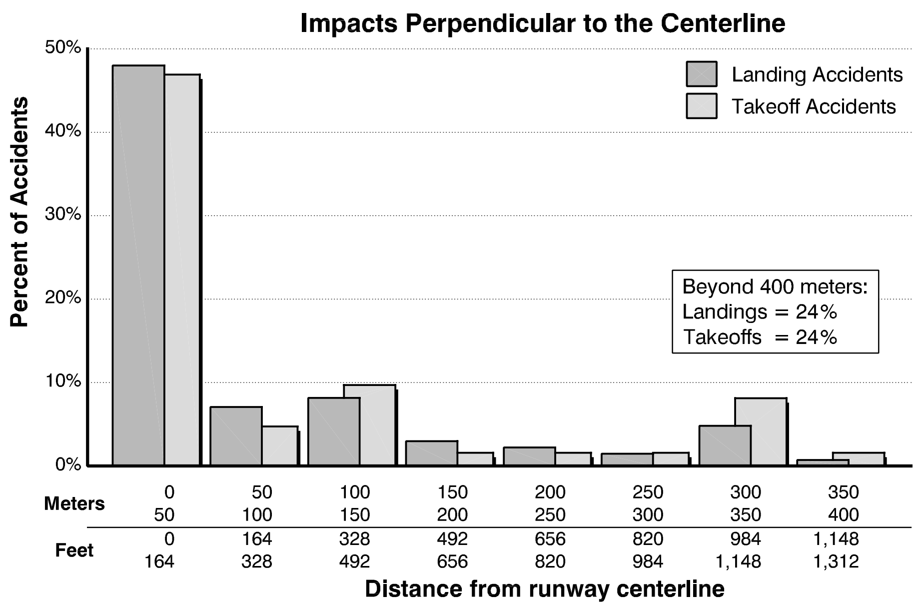
- **Report of the President's Airport Commission**—This commission, best known as the Doolittle Commission in honor of its chairman, James Doolittle, conducted one of the first comprehensive studies of the noise and safety relationships between airports and surrounding communities. The commission's 1952 report is valuable today for the historical perspective it gives to current airport compatibility issues. Among other things, the commission plotted the location of over 30 off-airport commercial and military aircraft crashes which caused death or injury to persons on the ground (there is no indication in the report that any data was gathered regarding non-injury accidents). Despite the rather limited database, the commission's report lead to the establishment of what became known as clear zones and are now called runway protection zones at the ends of airport runways.

See Chapter 9 for a description of APZs.

- **Department of Defense Air Installation Compatible Use Zone (AICUZ) Program**—The AICUZ program was established in 1973 as a joint effort of the several branches of the military. An element of the study leading to the creation of the program entailed assembly and analysis of data regarding the locations of military aircraft accidents around air bases. The data covered the period from 1968 through 1972 and included more than 300 major airfield-related accidents which occurred within 10 nautical miles of the runway. The study served to define areas of significant military aircraft accident potential, known as *Accident Potential Zones (APZs)*.

- **FAA Commercial Aircraft Accident Study**—A 1990 FAA study (*Location of Aircraft Accidents/Incidents Relative to Runways*) compiled data regarding the location of commercial aircraft accidents relative to the runway involved. Data was gathered by review of National Transportation Safety Board dockets containing the complete record of the board's investiga-





Notes:

- Data represents accidents involving commercial air carrier aircraft having a maximum authorized total weight of 4.0 metric tons or more. Locations are international and cover the period between 1970 and 1995.
- Takeoff and landing overrun accidents are excluded from this data.
- Landing percentages are based on 125 landing accidents occuring prior to the landing threshold; 55 landing accidents occurring beyond the threshold are excluded.
- Takeoff percentages are based on 62 takeoffs accidents; locations indicated are relative to the far (departure) end of the runway.

Source: National Air Traffic Services Limited, London; Third Party Risk Near Airports and Public Safety Zone Policy (1997)

FIGURE 8C

Runway Proximity of Air Carrier Accidents

International

tion of each accident. A total of 246 accidents and incidents occurring over a 10-year period (1978-1987) were included in the analysis. Of these, the majority (141) were limited to the immediate vicinity of the runway. Some 87 were classified as being either: a landing accident/incident in which the aircraft impacted with the ground more than 2,000 feet from the runway threshold; or a takeoff crash after the aircraft became airborne, but before it reached the first power reduction or VFR pattern altitude. Another 18 entries were landing undershoots occurring within 2,000 feet of the runway end. Figure 8D depicts the locations of the 16 landing (including 4 undershoots of more then 500 feet) and 23 takeoff accidents/incidents for which adequate locational data was available.

Theoretical Areas of High Accident Probability

Particularly useful in this regard is data on the phase of operation of aircraft at the time of an accident. Table 8A contains a summary of published NTSB data on this subject.

By examining the available data on types and locations of accidents in conjunction with information on airplane operational parameters as discussed earlier, it is possible to ascertain where accidents can theoretically be expected to occur most often.

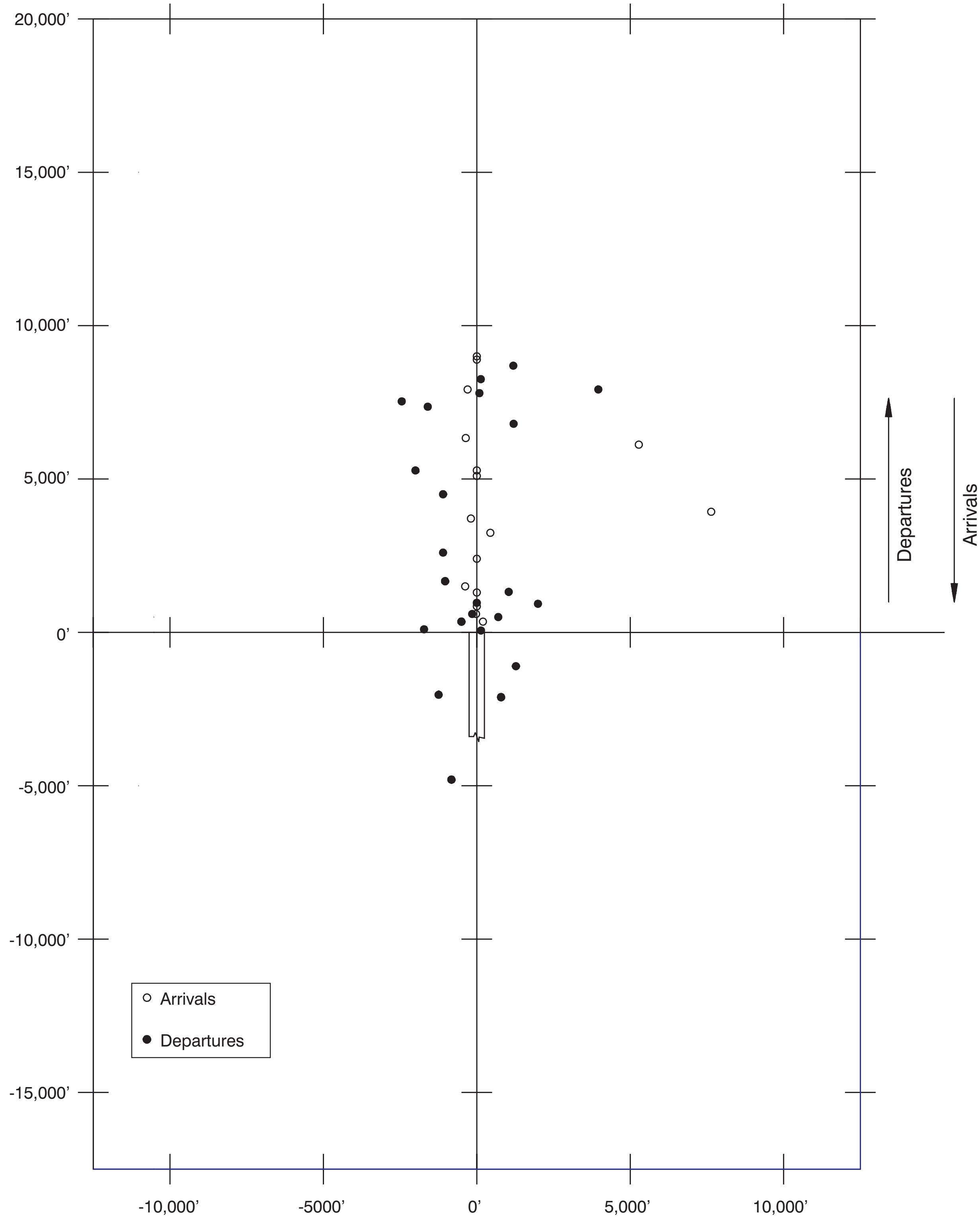
Approach/Landing Accidents

The great majority of general aviation aircraft landing accidents take place on or immediately adjacent to the runway. Indeed, NTSB data for the 1990 to 2000 period indicates that some three-fourths (77%) of all general aviation landing accidents occur during touchdown or roll-out (usually hard or long landings, ground loops, etc.). Although frequent in occurrence, these types of accidents seldom (less than 11% of the time) result in serious or fatal injuries.

The remaining 23% of general aviation landing accidents take place in the landing pattern, on final approach, or during a go-around attempt. A common circumstance that can result in an approach accident is pilot misjudgment of the aircraft descent rate and failure to add power soon enough to keep the aircraft in the air. Poor visibility, unexpected downdrafts, or tall objects beneath the final approach course can intensify this problem. Another prospective type of landing accident can occur if a pilot overshoots a turn from base to final and inappropriately cross controls the airplane rudder and ailerons while attempting to return to the runway alignment. The result can be a stall, spin, and uncontrolled crash.

The pattern for commercial aviation is less heavily weighted to the area on or near the runway (Table 8B). Accidents on or near the runway range from 64% for air carrier operations, to 51% for commuter operations, to 58% for air taxi operations.

These types of events all will tend to place the accident site fairly close to the extended runway centerline. Also, because lower altitude decreases the chances of successful recovery from unexpected conditions, accidents can be expected to be more common closer to the runway end than at points farther away.



Source: FAA Office of Safety Oversight (1990)

FIGURE 8D

Commercial Aircraft Accident Location Pattern

Phase of Operation	Percent of Total		Proportion Fatal/Serious	
Standing	1.1		34.6	
Taxi	3.5		11.0	
Takeoff	18.2		28.9	
In Flight				
Climb		2.8		46.3
Cruise		11.8		41.5
Descent		4.9		58.9
Maneuver		12.6		58.4
Total	32.1		46.3	
Landing				
Approach		10.0		42.5
Landing		33.9		11.3
Go-Around		0.3		27.3
Total	44.2		42.5	
Other/Unknown	0.9		83.6	
All Accidents	*100.0*		*31.4*	

Note: Data includes all (20,399) U.S. general aviation accidents by all aircraft types for the period 1990–2000.

Source: NTSB Aviation Accident Database—General Aviation, 1990–2000

TABLE 8A

Accidents by Phase of Operation

U.S. General Aviation Aircraft

Phase of Operation	FAR Part 121 Operations		Scheduled FAR Part 135 Operations		Nonscheduled FAR Part 135 Operations	
	Percent of Total	**Proportion Fatal/Serious**	**Percent of Total**	**Proportion Fatal/Serious**	**Percent of Total**	**Proportion Fatal/Serious**
Standing	10.3	11.4	7.0	4.3	2.3	2.3
Taxi	16.2	11.4	14.6	0.0	5.1	0.0
Takeoff	12.2	25.0	14.6	8.7	21.0	15.8
In Flight						
Climb	7.4	4.5	3.8	4.3	4.7	6.8
Cruise	18.5	13.6	9.7	23.9	21.8	30.6
Descent	10.3	0.0	5.9	4.3	3.0	4.9
Maneuver	1.1	0.0	5.9	13.0	8.1	12.8
Total	37.3	18.1	25.3	45.5	37.6	55.1
Landing						
Approach	7.0	15.9	16.8	37.0	13.3	21.5
Landing	12.2	4.5	17.8	0.0	18.7	2.6
Total	19.2	20.4	34.6	37.0	32.0	24.1
Other/Unknown	4.8	11.4	3.8	4.3	1.9	2.6
All Accidents	*100.0*		*100.0*		*100.0*	

Source: NTSB Aviation Accident Database—Air Carrier, 1986–1995

TABLE 8B

Accidents by Phase of Operation

U.S. Air Carrier Aircraft

Takeoff/Departure Accidents

Unfortunately, since 1990 NTSB has not distinguished between the various phases of takeoff in presenting accident data. Therefore, the latest available data is described here.

Data from the period 1974-1989 indicates that the greatest proportion of general aviation takeoff/departure accidents (some 65%) take place during the initial climb phase. (Equivalent data for commercial aviation is not available.) This finding is consistent with two factors:

- Aircraft engines are under maximum stress during the initial climb phase and thus somewhat more susceptible to mechanical problems than at other times; and
- On average-length runways, once an aircraft has begun to climb, it is often too late to make an emergency landing and stop on the runway without overshooting the far end.

With respect to where takeoff accidents occur, a much greater dispersion of sites can be hypothesized than is the case for landings. Landings all involve aircraft descending at similar angles toward about the same point on the runway. By comparison, more variables affect the three-dimensional path of aircraft takeoffs, even under normal conditions. For one, climb rates and other takeoff performance characteristics differ substantially from one aircraft type to another. Also, even for similar types of aircraft, the flight track and the altitude above any given point along it will vary depending upon the aircraft payload, piloting techniques, and the intended direction of flight after takeoff.

The differences in performance characteristics of single-engine versus twin-engine propeller airplanes is particularly illustrative.

➤ **Single-Engine Airplanes**—For single-engine airplanes, a high percentage of accidents can be expected to occur within 7,000 to 9,000 feet of the start of takeoff roll. This distance is calculated based upon an assumed occurrence of an engine failure at an altitude of 500 feet with the aircraft then gliding back down to the ground (and also assuming the ground level to be equal to that of the runway). As previously discussed, at altitudes above 500 feet, it should be possible to return to the runway for an emergency landing and most pilots will attempt to do so rather than continue straight ahead. At lower altitudes, the most prudent pilot action is to seek a landing site as close to straight ahead as practical.

➤ **Twin-Engine Airplanes**—With a twin-engine piston airplane, an engine failure on takeoff does not necessarily mean that the aircraft will immediately glide back toward the ground. The altitude at engine failure and the manner in which the remaining engine is operated thus add more variables to where the plane can be most expected to put down. If an engine failure occurs at or below best single-engine rate of climb speed (V_{yse}), the aircraft would normally be just airborne and controllable, but sometimes unable to climb. At these low speeds, the proper pilot action should be to reduce or shut off power to the remaining engine and glide back to the ground as would a single-engine airplane. At speeds slightly above V_{yse}, twin-engines airplanes may theoretically be capable of climbing, but for a pilot to make this happen under emergency conditions is difficult. Sometimes, a pilot will try to maintain power in the functioning engine, but then lose directional control of the aircraft and crash. A relatively wide dispersal of accident sites—both in distance from the start of takeoff and to either side of the extended runway centerline—can thus be predicted in theory.

Recent Research

In order to obtain accident location data for general aviation aircraft, basic new research was conducted for the 1993 edition of this *Handbook*. After investigating several possible data sources—principally direct contact with individual airports versus review of the NTSB *Factual Reports*—the latter method was found to provide the most complete and consistent data. The research was conducted by the Institute of Transportation Studies at the University of California, Berkeley. For the 2002 edition of the *Handbook*, this database was expanded. The current database resulting from this research:

- Encompasses all 50 states (although several have no accidents represented);
- Covers a time period from 1983 into 1992;
- Contains data only on accidents, not incidents;
- Contains a total of 873 aircraft accident records (445 arrivals and 428 departures); and
- Includes all types of general aviation airplanes, but not airline air craft, helicopters, or other aircraft types (ultralights, blimps, etc.), or military aircraft.

See Appendix E for a more complete description of the data sources considered, the research methodology employed, and the specific data included in the database.

A somewhat broad definition of airport vicinity was used for the purposes of this research. Airport size was recognized as being a significant determinant of whether an accident site a certain distance beyond the runway is on or off the airport property. Consequently, all accidents not confined to the immediate vicinity of the runway or its associated safety zones are included in the database. For the outer boundary of the airport vicinity, a 5-mile radius—measured from the airport center in accordance with the NTSB data format—was selected.

AIRCRAFT ACCIDENT LOCATION PATTERNS

The following paragraphs highlight notable findings from the expanded general aviation accident database. Comparative data from other sources is indicated where applicable. Table 8C presents a numeric summary of the percentages of various categories of accidents represented in the database. Selected distance data is listed in Table 8D. Table 8E summarizes some comparative NTSB accident data for all U.S. general aviation aircraft accidents, both on-airport and off. Similar NTSB data for air carrier accidents is contained in Table 8F.

Category Accidents Involving:	All Accidents		Arrival Accidents		Departure Accidents	
Total Database	873	100.0%	445	100.0%	428	100.0%
Runway Length						
Less than 4,000 ft.	344	39.4%	153	34.4%	191	44.6%
4,000 ft. to 5,999 ft.	281	32.2%	150	33.7%	131	30.6%
6,000 ft. or more	248	28.4%	142	31.9%	106	24.8%
Unknown	0	0.0%	0	0.0%	0	0.0%
Approach Type						
Visual Approaches			343	77.1%		
Nonprecision Approaches			27	6.1%		
Precision Approaches			70	15.7%		
Unknown			5	1.1%		
Time						
Dawn	10	1.1%	7	1.6%	3	0.7%
Day	603	69.1%	262	58.9%	341	79.7%
Dusk	37	4.2%	29	6.5%	8	1.9%
Night	222	25.4%	147	33.0%	75	17.5%
Unknown	1	0.1%	0	0.0%	1	0.2%
Weather Conditions						
VFR	688	78.8%	328	73.7%	360	84.1%
IFR	182	20.8%	117	26.3%	65	15.2%
Unknown	3	0.3%	0	0.0%	3	0.7%
Aircraft Type						
Single-Engine Propeller	636	72.9%	305	68.5%	331	77.3%
Twin-Engine Propeller	235	26.9%	140	31.5%	95	22.2%
Business Jet	2	0.2%	0	0.0%	2	0.5%
Pilot Control						
Some	164	18.8%	71	16.0%	93	21.7%
None	665	76.2%	357	80.2%	308	72.0%
Unknown	44	5.0%	17	3.8%	27	6.3%
In-Flight Collision with Object						
Yes	280	32.1%	148	33.3%	132	30.8%
No	593	67.9%	297	66.7%	296	69.2%
Aircraft Damage						
Destroyed	568	65.1%	260	58.4%	308	72.0%
Substantial	303	34.7%	185	41.6%	118	27.6%
Unknown	2	0.2%	0	0.0%	2	0.5%
Consequences						
Onboard Fatalities	463	53.0%	212	47.6%	251	58.6%
Ground Fatalities	6	0.7%	2	0.4%	4	0.9%
Onboard Serious Injury	228	26.1%	104	23.4%	124	29.0%
Ground Serious Injury	6	0.7%	2	0.4%	4	0.9%
Traffic Pattern Direction						
Left	684	78.4%	353	79.3%	331	77.3%
Right	117	13.4%	59	13.3%	95	13.6%
Unknown	72	8.2%	33	7.4%	2	9.1%

Note: Numbers in each category may not add to 100% because of mathematical rounding or missing data in some records.

TABLE 8C

Accident Characteristics: Proportions

General Aviation Aircraft Accident Database

	Mean Distances (Feet)			
	All Operations	**Arrivals**	**Departures**	**Normalized Departures**
Runway Length				
All Categories	4,938	5,152	4,715	
Accident Location				
All Categories		2,801	5,514	799
Aircraft Type				
Single-Engine		2,092	4,959	669
Twin-Engine		4,347	7,446	1,320
Pilot Control				
Some		2,422	5,581	1,083
None		2,767	5,404	562
Visibility				
VFR		1,716	5,196	700
IFR		5,844	7,150	1,152
Time of Day				
Dawn/Daylight/Dusk		2,006	5,038	594
Night		4,430	7,681	1,813
Swath Length				
All Accidents	197	236	158	
Pilot Control				
Some	220	186	244	
None	183	231	130	

	Median Distances (Feet)			
	All Operations	**Arrivals**	**Departures**	**Normalized Departures**
Runway Length				
All Categories	4,600	4,997	4,300	
Accident Location				
All Categories		1,000	4,684	600
Aircraft Type				
Single-Engine		520	4,177	500
Twin-Engine		2,276	6,946	1,131
Pilot Control				
Some		1,320	4,753	779
None		788	4,561	478
Visibility				
VFR		475	4,427	500
IFR		4,200	7,051	1,738
Time of Day				
Dawn / Daylight / Dusk		500	4,417	500
Night		2,798	7,337	1,481
Swath Length				
All Accidents	100	145	75	
Pilot Control				
Some	144	135	147	
None	89	140	54	

Notes:

- All distances rounded to nearest 10 feet.
- Accident location distances calculated along runway centerline, ignoring offset to left or right. Arrival distances measured from landing threshold; departure distances measured from start of takeoff roll; normalized departure distances from departure (climb-out) end of runway.
- Information on the degree of pilot control at the time of aircraft contact with the ground is unknown for many accidents, including some for which swath length data was available. This factor accounts for the “all accidents” swath length exceeding the lengths for both “some” pilot control and “none.”

TABLE 8D

Accident Characteristics: Distances

General Aviation Aircraft Accident Database

	Percent of Total Accidents	Proportion Fatal/Serious
Time of Day		
Dawn/Daylight/Dusk	85.6 [a]	28.5 [a]
Night	14.4	45.0
Weather Conditions		
VFR	55.5 [a]	26.4 [a]
IFR	45.5	46.7
Aircraft Damage		
Destroyed	25.3 [a]	
Substantial	72.5	
Minor/None	2.2	
Type of Injuries		
Fatal	19.7 [a]	
Serious	11.3	
Minor/None	69.0	
Aircraft Damage		
Single-Engine Airplanes	89.1 [b]	17.2 [b]
Twin-Engine Airplanes	8.9	29.9
Turboprop	0.5	32.0
Business Jet	8.3	15.0
Helicopter	2.8	11.5
Other	1.5	34.4

Notes:

- Comparable data not available for all years. Data shown is tabulated for the following years:
  [a] 1990–2000 [b] 1975–1997
- Data includes all general aviation accidents, both on- and off-airport.

Source: [a] *Data compiled from NTSB, Aviation Accident Database (1990–2000) and*
[b] *Annual Review of Aircraft Accident Data (1997)—General Aviation*

TABLE 8E

Selected NTSB Accident Data

U.S. General Aviation Aircraft

	Percent of Total Accidents	Proportion Fatal/Serious
Time of Day		
Dawn/Daylight/Dusk	60.7	29.7
Night	39.3	29.6
Weather Conditions		
VFR	33.4	29.4
IFR	66.6	28.3
Aircraft Damage		
Destroyed	16.7	
Substantial	42.2	
Minor/None	41.1	
Type of Injuries		
Fatal	15.6	
Serious	14.4	
Minor/None	70.7	

Notes:

- Comparable data not available for all years. Data shown is tabulated for the years 1990–2000.
- Data includes all air carrier accidents, both on- and off-airport.

Source: Data compiled from NTSB, Aviation Accident Database (1990–2000)

TABLE 8F

Selected NTSB Accident Data

U.S. Air Carrier Aircraft

The complete set of general aviation accident location pattern exhibits, including depiction of the various data subsets discussed in this section, are found in Appendix F.

The spatial distribution of general aviation aircraft arrival and departure accidents is illustrated in Figures 8E, 8F, and 8G. As described below, the departure accident location patterns are presented in two different formats.

Arrival versus Departure Difference

See Appendix E, Exhibit E-1, for the criteria used to distinguish between arrivals and departures for circumstances such as touch-and-goes and missed approaches.

The first question assessed in review of the accident location data was to determine how the pattern of aircraft landing accidents differs from the pattern for takeoff accidents. An important issue in this analysis is what point to use as a common reference within each of these accident categories.

➤ **Arrivals**—For landing accidents, this decision is easy. The landing threshold, whether it be the actual runway end or a displaced threshold, is the relevant point. Figure 8E and Exhibit F-1 illustrate the spatial distribution of all arrival accidents occurring within 25,000 feet of the runway landing threshold.

As used herein, the departure end of the runway is the end which the aircraft passes on takeoff and climb-out.

➤ **Departures**—For takeoffs, two choices of common reference point are apparent: the beginning point of the takeoff roll and the departure end of the runway. Except for touch-and-goes and intersection departures, the runway length represents the difference between the two points. Each of these choices has theoretical merits as to the utility of the information provided.

- Measuring from the start of takeoff roll recognizes the fact that, once an aircraft is airborne, the location of many accidents is independent of the runway length.
- On the other hand, circumstances resulting in an accident 2,000 feet beyond the end of a 5,000-foot runway might result in nothing more than an emergency landing on a 10,000-foot runway. *Normalizing* the data by measuring from the departure end of the runway thus takes into account the significance of runway length in many departure accidents.

Figure 8F and Exhibit F-2 plot the departure accidents relative to the start of takeoff roll. Figure 8G and Exhibit F-3 show the normalized location pattern. As can be expected, the clustering of points is much tighter when measured from the departure end of the runway.

The total number of accidents in the database is split almost equally between arrivals and departures. By comparison, NTSB data indicates that general aviation landing accidents occur about twice as often as takeoff accidents (Table 8A). The substantial number of landing accidents which take place on or near the runway accounts for most of this difference. Since these accidents do not have land use compatibility implications, they are not included in the *Handbook* database.

Effects of Runway Length

See Appendix F for these exhibits.

Another means of factoring out the runway length variable for departure accidents is to individually assess the location distributions associated with

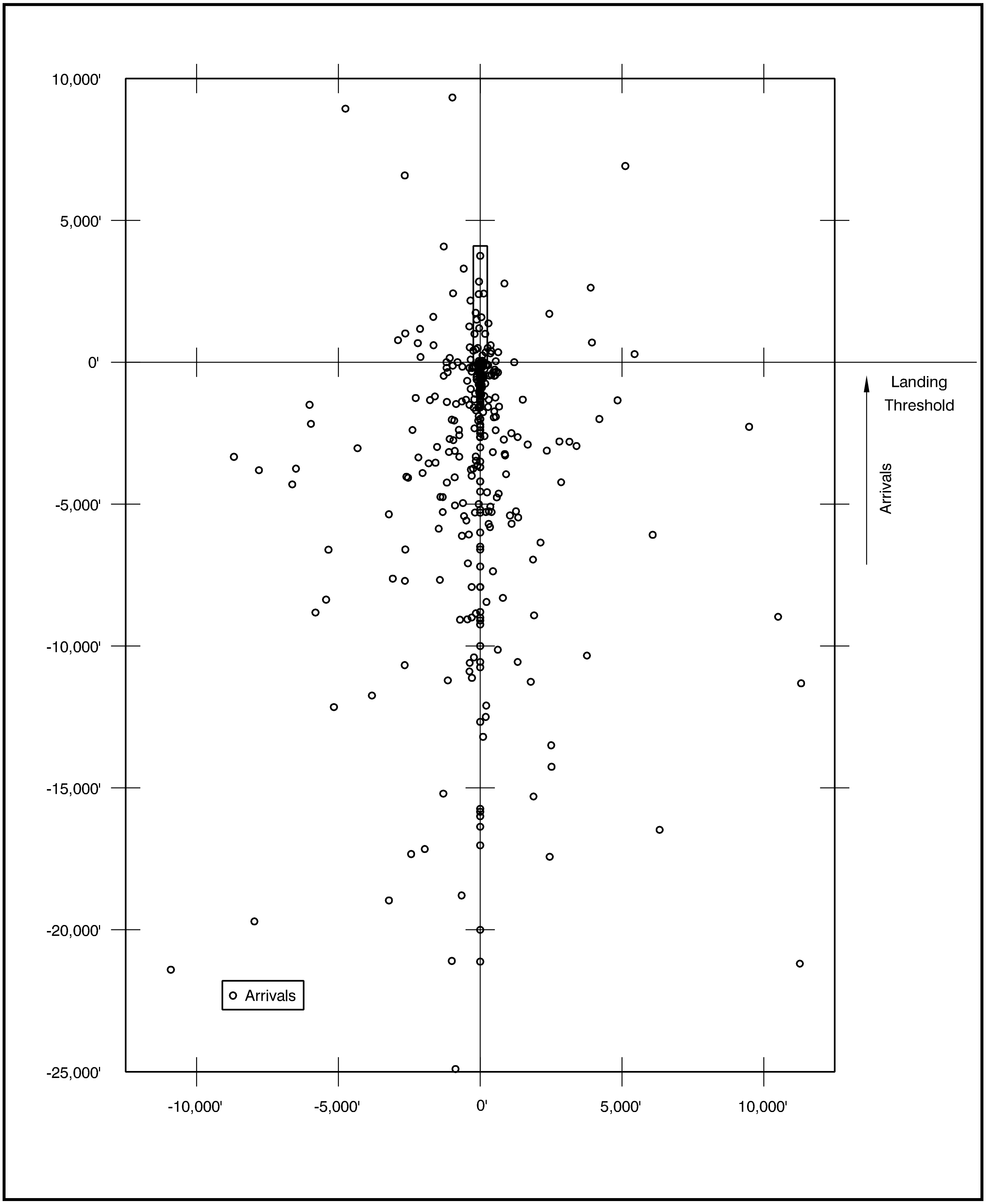


FIGURE 8E

Arrival Accidents

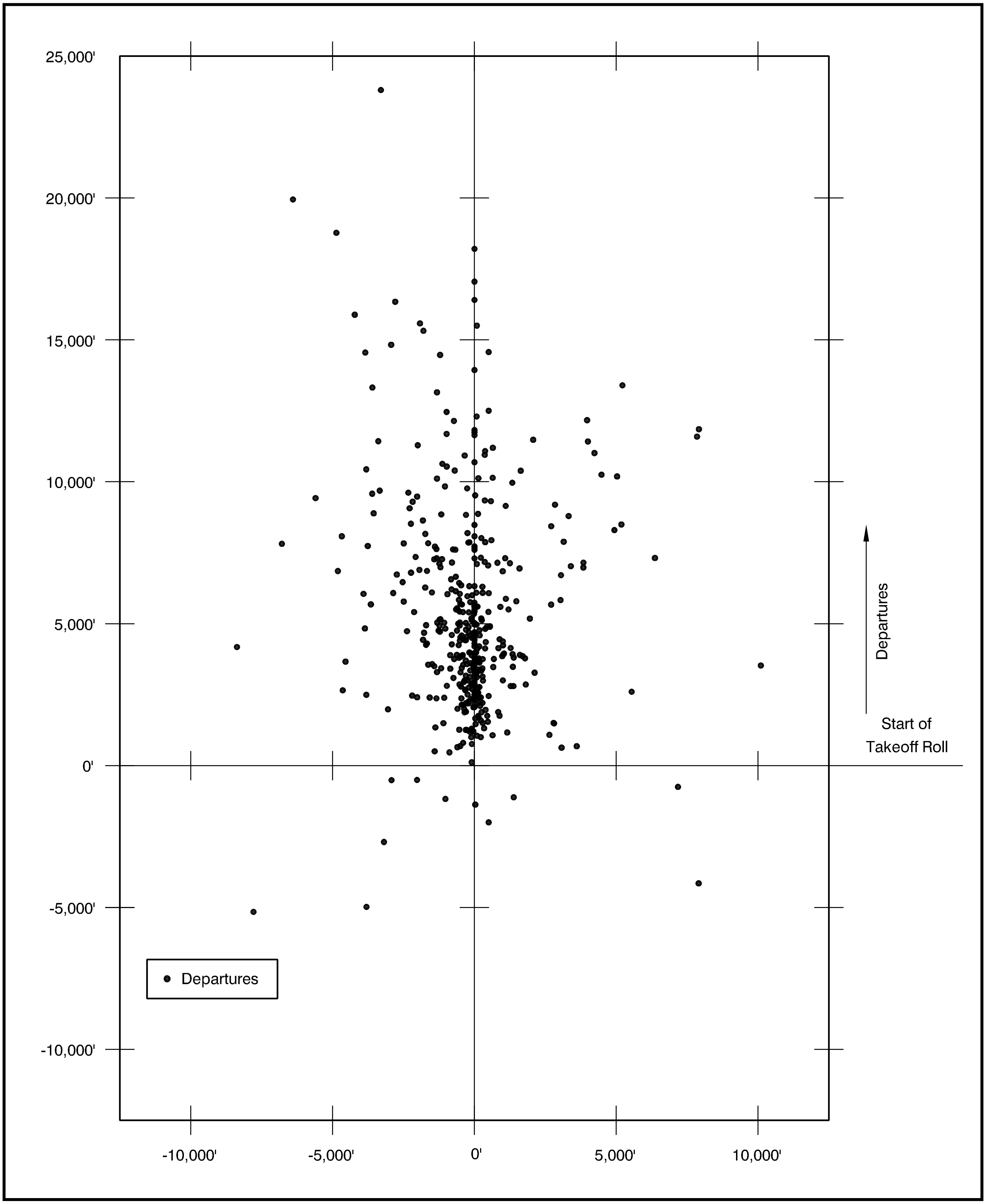


FIGURE 8F

Departure Accidents

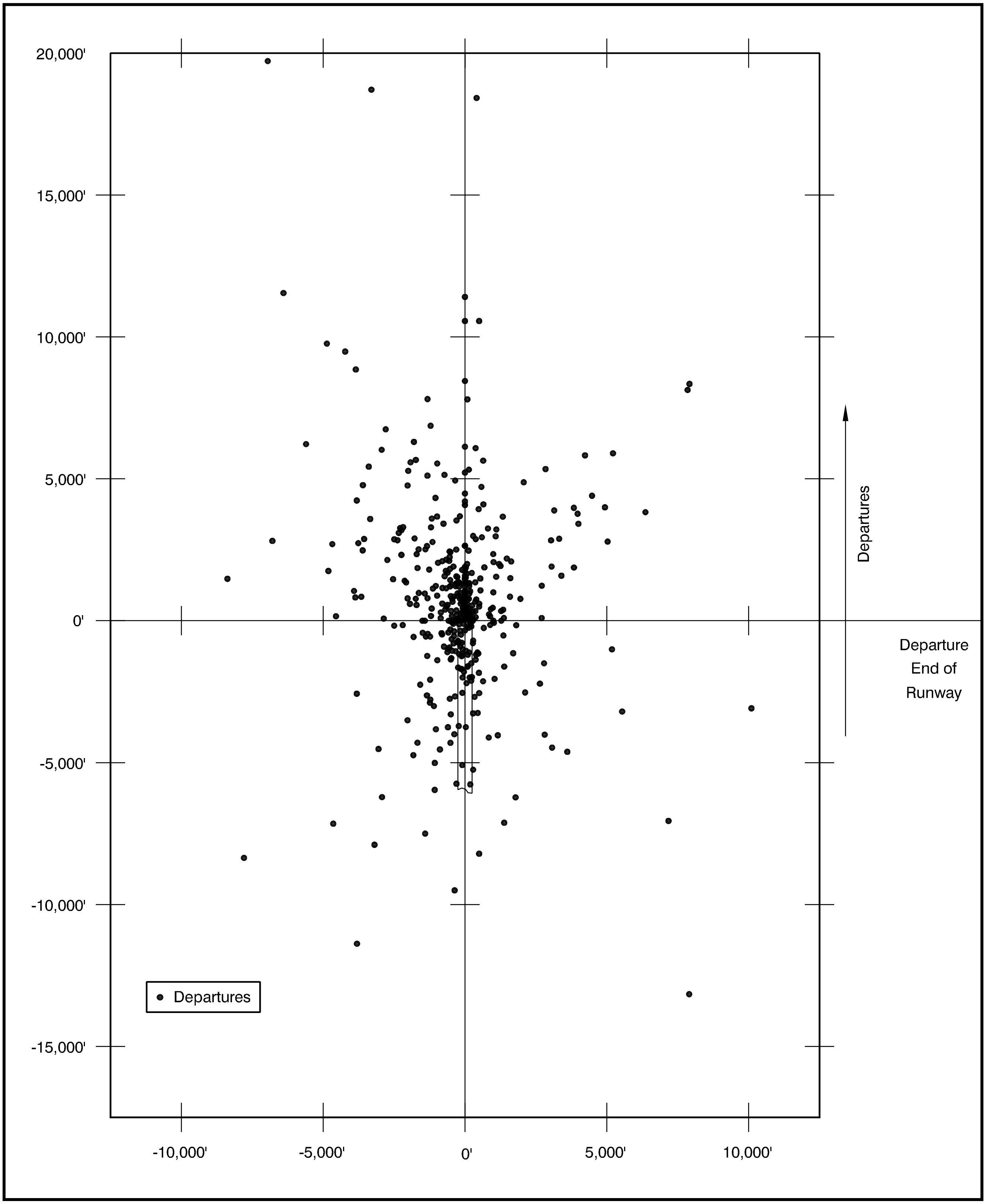


FIGURE 8G

Departure Accidents, Normalized

different length runways. Exhibits F-4, F-5, and F-6 illustrate the results for runway lengths of less than 4,000 feet, 4,000 to 5,999 feet, and 6,000 feet or more, respectively. The sites of the departure accidents are plotted with respect to the start of takeoff roll.

One finding apparent from these illustrations is that the longer the runway, the greater the spread of departure accident locations. Nevertheless, the locations tend to be most closely bunched around the end of the median length runway in each of these groups.

Another, perhaps somewhat surprising, variable revealed by the three charts is that arrival accidents also are more spread out for longer runways than for shorter ones. A review of the data suggest several possible explanations for this phenomenon:

- Almost half (49%) of all accidents on runways of 6,000 feet or more are by twin-engine aircraft compared to only 12% on runways under 4,000 feet.
- Long runways have more IFR accidents—44% for runways of 6,000 feet or more, 4% for runways of less than 4,000 feet.
- Similarly, for nighttime accidents, more occur on long runways (45%) than on short ones (16%).

Aircraft Type Variables

Single-Engine Propeller Airplanes

Exhibit F-7 illustrates the pattern of off-airport landing and takeoff accidents by single-engine propeller airplanes. As hypothesized above, the accident locations tend to be clustered close to the runway ends and also relatively near the extended centerline. For approach/landing accidents, the median distance is 520 feet from the landing threshold. For takeoffs/departures, the median distance is 500 feet from the departure end of the runway and 4,177 feet from the start of takeoff roll. Also, almost 90% of the departure accident points lie within 9,000 feet of the start of takeoff roll.

Not certain from the accident records is whether accident locations reported as being on the extended runway centerline might actually be several hundred feet off to the side, especially for accidents occurring some distance from the runway end. It is apparent from NTSB reports that precision in terms of accident site location was not a high-priority objective. Every effort was made in the review of the records to determine the accident location as precisely as possible, but the actual number of points truly on centerline is probably less than shown in the database.

Multi-Engine Airplanes

The database indicates that the accident locations for twin and other multi-engine airplanes, including jets, are comparatively more stretched out than those for single-engine airplanes. Exhibit F-8 depicts the distribution. The majority of the approach/landing accidents are within 500 feet of the extended runway centerline, but the median distance is more than 2,200 feet from the landing threshold. The takeoff/departure accidents are widely scattered as conjectured in the earlier discussion of aircraft and pilot performance during emergencies. Although the median accident site distance is some 1,100 feet from the departure end of the runway, the sites are spread about evenly in the 5,000 to 10,000-foot range measured from the start of takeoff roll.

Airline Aircraft

The project database does not include airline aircraft accidents. For an assessment of these accidents, reference should be made to the FAA commercial aircraft accident study cited earlier in this chapter.

Helicopters

Data comparable to that presented here for airplanes may exist in NTSB *Factual Records*, but has not been compiled in any published source. The most detailed assessment of helicopter accident locations currently available is one documented in two reports prepared for the Federal Aviation Administration—*Analysis of Helicopter Mishaps at Heliports, Airports, and Unimproved Sites* and *Analysis of Helicopter Accident Risk Exposure near Heliports, Airports, and Unimproved Sites* (SCT–1991 and SCT–1992). This study found that (between 1977 and 1986) some 37% of helicopter accidents took place on or within 1 mile of a landing site whether it be at an airport, a heliport, or other location. Among all types of helicopter mishaps (accidents plus incidents), 60% involved obstruction strikes—38% at the landing site and 22% within 1 mile. The majority of the latter group were wire strikes and in each case the wires were unmarked. This finding lead the authors of the study to recommend the marking of wires and other objects within a buffer zone below the standard 8:1 approach/departure surface slope of helicopter facilities.

Three additional observations are worth noting regarding helicopter accident locations:

- Because helicopter landing sites are small, a substantial proportion likely occur, or affect locations, beyond the landing site boundaries.
- Helicopters can take off and land in almost any direction from a heliport, obstacles and wind direction permitting.
- Beyond the immediate vicinity of the landing site, helicopter flight tracks may be widely divergent unless specific procedures are established for a given airport or heliport (the FAR Part 77 approach/departure surface for helicopter landing pads is 4,000 feet in length).

Pilot Control Variables

In the discussion of emergency procedures earlier in this chapter, the point was made that a pilot will, if possible, normally attempt to steer the aircraft to an open area when an emergency landing is unavoidable. A general assumption has been that most aircraft are under some control when forced down. The extent of pilot control was therefore one of the variables assessed in the review of the accident Factual Records.

The results of the research were surprising: in over three-fourths of the cases included in the database, the aircraft was not under control when it hit the ground. A probable explanation for this number being so high is that the database includes only accidents, not incidents. Thus, if a pilot makes a successful emergency landing without causing serious injuries or substantial damage, the event is classified as an incident and does not appear in NTSB records even if the landing site is not an airport runway.

Exhibits F-9 and F-10 show the location patterns for accidents in which there was some pilot control and no pilot control, respectively.

Other Variables

Weather Conditions

Exhibits F-11 and F-12 show the respective distributions of accidents which took place during visual flight rules (VFR) weather conditions versus those occurring during instrument flight rules (IFR).

A comparison of the two figures indicates that IFR arrival accidents tend to occur farther from the end of the runway than VFR accidents do—a median distance of nearly 4,200 feet from the runway approach end for IFR arrivals versus 475 feet for VFR landings.

Time of Day

NTSB data (for 1990 to 2000) reveals that approximately 86% of all general aviation accidents and 61% of commercial aircraft accidents take place during dawn, daylight, or dusk, with about 14% general aviation accidents and 39% of commercial aviation accidents occurring in hours of darkness (officially, one hour after sunset to one hour before sunrise). No definitive data is available on the percentage of aircraft takeoffs and landings made at night. A reasonable estimate is 7% to 10%, although the number varies substantially from one airport to another. The higher incidence of commercial aviation accidents at night is consistent with the expected greater number of commercial operations at night.

Of all the accidents in the *Handbook* database, approximately 25% took place at night. Moreover, nighttime accounted for over 30% of the arrival accidents in the database. If these figures are representative of all off-airport accidents, they suggest that nighttime increases the propensity for accidents to occur beyond the runway environment.

Exhibits F-13 and F-14 show the locational distributions of dawn/daylight/dusk versus nighttime accident sites. As can be seen, the nighttime accident sites are generally farther from the runway than are the daytime accident sites—the median is some 2,300 feet greater for arrivals and 980 feet more for departures.

Single-Sided Traffic Patterns

For most runways, aircraft make left-hand turns as they approach for landing or when they takeoff and remain in the traffic pattern. On some runways, any of a variety of factors may dictate a right-hand pattern. Accidents in the *Handbook* database include a mixture of both situations. A reasonable expectation is that the distribution of accident sites would look somewhat different around runways which have the traffic pattern only on one side.

Surprisingly, though, no significant difference is apparent from a comparison between Exhibit F-15 which shows accidents for runways indicated to have left-hand patterns and Exhibits F-1 and F-2 which represent all accidents.

NATURE OF IMPACT

The nature of the impact that occurs when a small aircraft comes down off airport can vary from a nearly normal landing to a catastrophic crash. When the aircraft remains under control and a reasonably open emergency landing site can be found, the impact can be relatively minor—the potential for injury to people on the ground is small and the aircraft occupants have a strong probability of surviving. The most serious accidents, in terms of risks to people on the ground as well as to the aircraft occupants, are those in which the pilot either:

- Loses control of the aircraft and, because of damage, low altitude, or improper procedures, is unable to regain control; or
- Is unable to select a reasonable forced landing spot because of darkness, fog, or the nonexistence of such a spot.

The following discussion examines available data and theoretical findings regarding the nature of the impact from an aircraft accident.

Severity

As can be expected, off-airport aircraft accidents tend to be more severe than those occurring on or near a runway. The accident database summary (Table 8C) indicates that the aircraft is destroyed in some 65% of off-airport accidents. Moreover, fatal injuries occur about half of the time—48% for arrival accidents and 59% for departure accidents. By comparison, NTSB data (Table 8E) shows that for all accident locations, the rates for destroyed aircraft and fatal injuries have been only 25% and 20%, respectively. In commercial aviation accidents, the rates are slightly lower: in 17% of accidents the aircraft is destroyed and in 16% a fatality occurs (Table 8F).

It must be remembered, however, that these figures are relative to the total number of *accidents*. No information is available regarding how often aircraft make an emergency landing on or off of an airport without incurring substantial damage or resulting in serious or fatal injuries. Nevertheless, the percentage involving severe consequences is undoubtedly much less when all mishaps (incidents as well as accidents) are taken into account.

Darkness and poor weather both adversely affect the severity of accidents. According to NTSB data, about 29% of dawn/daylight/dusk accidents involving general aviation aircraft result in serious or fatal injuries, compared to nearly 45% of the night accidents. About 30% of commercial aviation accidents during the dawn/daylight/dusk period result in fatalities or serious injuries with about the same percentage at night. Likewise, general aviation IFR accidents have serious or fatal results about half (47%) of the time, whereas only a quarter (26%) of VFR accidents have such severe consequences.

General Aviation Aircraft Accident Swath

Swath length is defined as the distance between where an aircraft first touched the ground or an object on the ground and where it subsequently came to a rest.

One of the variables examined during the review of NTSB accident re cords was the swath length associated with each accident. Adequate information with which to assess this factor was available in only about 53% of the Factual Records. Among the conclusions reached regarding the accidents represented in the database are:

- The median swath length for all general aviation accidents is only about 100 feet.
- Accidents in which the aircraft was under some pilot control typically have longer swath lengths (144 feet on average) than those where the aircraft was out of control (an average of 89 feet).

Accidents Involving Collisions with Objects

Aircraft collisions with objects on the ground can be the cause of accidents or simply a secondary factor in the consequences of the event. Historically, the NTSB's annual reviews of general aviation accident data included counts of accidents in which objects were a cause or factor. Unfortunately, the NTSB discontinued the detailed documentation of this information in 1990. Therefore, the most current data available have been used (1982-1989). Table 8G presents a summary of this data.

In evaluating the data's significance, several points should be recognized:

- The data includes accidents involving all types of aircraft helicopters, hot air balloons, etc.), not just airplanes.
- The location of the objects involved may be either on or off airport.
- The counts include accidents during all phases of aircraft opera tion—taxiing accidents, as well as those during approaches, departures, or en route.
- No distinction is made between accidents in which the objects listed were the cause versus ones in which they were only involved in a secondary manner.
- The severity of the accidents is not reflected in the data.

A particularly noteworthy finding of the data is the relative rarity of accidents involving residences or other buildings. For an 8-year period (1982–1989), the annual average was only 8.1 for residences and 9.9 per year for other buildings. These numbers represent 0.3% and 0.4% of total accidents, respectively. An earlier study by the Aircraft Owners and Pilots Association (AOPA–1985) for the years 1964–1982 showed a higher average number of collisions with residences and other buildings—a total of 29.6 per year (also summarized in Table 8E). However, more aircraft operations, as well as nearly 65% more accidents, took place annually during that period compared to the more recent data. The percentage of annual accidents involving residences and buildings thus averages only about 0.65% in both data sets.

Considering that the *Handbook* database contains only near-airport accidents and only those for which precise location data was available, the results are consistent with the NTSB data. Over the 10-year period covered

	Average Number/Year	% of Category	% of All Accidents
Accidents Involving Objects on the Ground (1982–1989) [a]			
Type of Object Involved			
Residences	8.1	1.4	0.3
Other Buildings	9.9	1.7	0.4
Fences/Walls	88.0	15.1	3.2
Poles/Towers	26.4	4.5	1.0
Wires	108.3	18.6	3.9
Trees	242.5	41.7	8.8
Other Objects	98.3	16.9	3.6
Total - All Objects	581.4	100.0	21.2
All Accident Types	2,742.0		100.0
Accidents Involving Buildings and Residences (1964–1982) [b]			
Phase of Flight			
On-Ground	9.1	30.8	0.20
Traffic Pattern	17.8	60.1	0.40
In-Flight	2.7	9.1	0.06
Total	29.6	100.0	0.66
Type of Injuries On-Board or On-Ground			
Fatal	3.7	12.5	0.08
Serious	4.4	14.9	0.10
Minor/None	21.5	72.6	0.48
Total	29.6	100.0	0.66
Type of Injuries to People On-Ground			
Fatal	0.5	27.8	0.011
Serious	0.6	33.3	0.013
Minor/None	0.7	38.9	0.016
Total	1.8	100.0	0.040
All Accident Types (1964–1982)	4,510.0		100.0
Type of Injury			
Fatal	1.8	28.7	
Serious	1.3	20.5	
Minor/None	3.3	50.8	
Total	6.4	100.0	

Source: [a] *NTSB, Annual Review of Aircraft Accident Data—General Aviation, 1982–1989*
[b] *Aircraft Owners and Pilots Association (1985)*

TABLE 8G

Accidents Involving Objects or People on the Ground

by the database, some 30 of the 873 accidents involved a collision with a residence (3.0 per year) and 18 involved other buildings (1.8 per year).

Effects of an Aircraft Collision with a Building

Data regarding the probable effects of a small aircraft colliding with a typical house or other small building is documented in a 1985 study (H&S–1985). The research entailed a search for previous studies on the subject, review of historical accident records, and interviews with building demolition experts and aircraft salvage companies. Consider-ation was also given to what effects might theoretically be predicted.

Variables

The consequences of an aircraft collision with a building were found to be affected by many variables. Among the primary ones are:

- The aircraft weight;
- The amount of fuel on board;
- The speed of the aircraft, both horizontally and vertically, at the time of the collision;
- The angle of contact with the structure (i.e., glancing or head-on);
- The aircraft attitude when the collision occurs;
- The extent of aircraft disintegration upon impact;
- The type of building construction, particularly the composition of the surface struck by the aircraft; and
- The occurrence and extent of fire after the impact.

Conclusions

The study determined that the combination of these variables is so great as to preclude definitive conclusions. The effects can only be estimated within a wide range of possibilities. To the extent that any meaningful conclusions can be reached from the data obtained, they can be summarized as follows:

➤ **Significance of Aircraft Size**—Other factors being equal (which, for any two accidents, they never are), more damage will be produced by larger, faster aircraft than by smaller and slower ones. The amount of kinetic energy produced by a small, but fully loaded, single-engine airplane flying at minimum speed is equivalent to that of a small automobile traveling at about 55 miles per hour. By comparison, a cabin-class twin would generate kinetic energy similar to that of a loaded 10-ton truck traveling 60 miles per hour (McElroy–1973).

➤ **Aircraft Design Factors**—Unlike automobiles, aircraft are not de signed to remain intact in collisions. The disintegration of the wings and fuselage of a small, general aviation aircraft as it collides with a building dissipates much of the kinetic energy that would otherwise be delivered to the structure.

➤ **Frequency of Occurrence**—As stated above, general aviation aircraft collisions with buildings of any kind, and residences in particular, happen infrequently.

- ➤ **Range of Consequences** — *When* an aircraft collides with a small building, the results can range from insignificant to catastrophic. Neither data nor analyses can predict the actual effects of a particular incident.

Non-Occupant Injuries

Injuries to people on the ground (i.e., people who are not occupants of the aircraft) as a result of general aviation aircraft accidents occur even less frequently than collisions with buildings. Most such incidents take place on-airport. National data on injuries to people in residences and other buildings over a 19-year period is summarized in the previously referenced Table 8G. Over the period examined, only 3.1 accidents per year resulted in fatal or serious injuries to people in a building.

A direct comparison with accidents in the *Handbook* database cannot be made because the database includes only off-airport accidents and does not distinguish between people in buildings and elsewhere on the ground. Nevertheless, the results show a similarly infrequent occurrence of people on the ground being seriously or fatally injured by an aircraft accident. Only 12 such accidents are in the database.